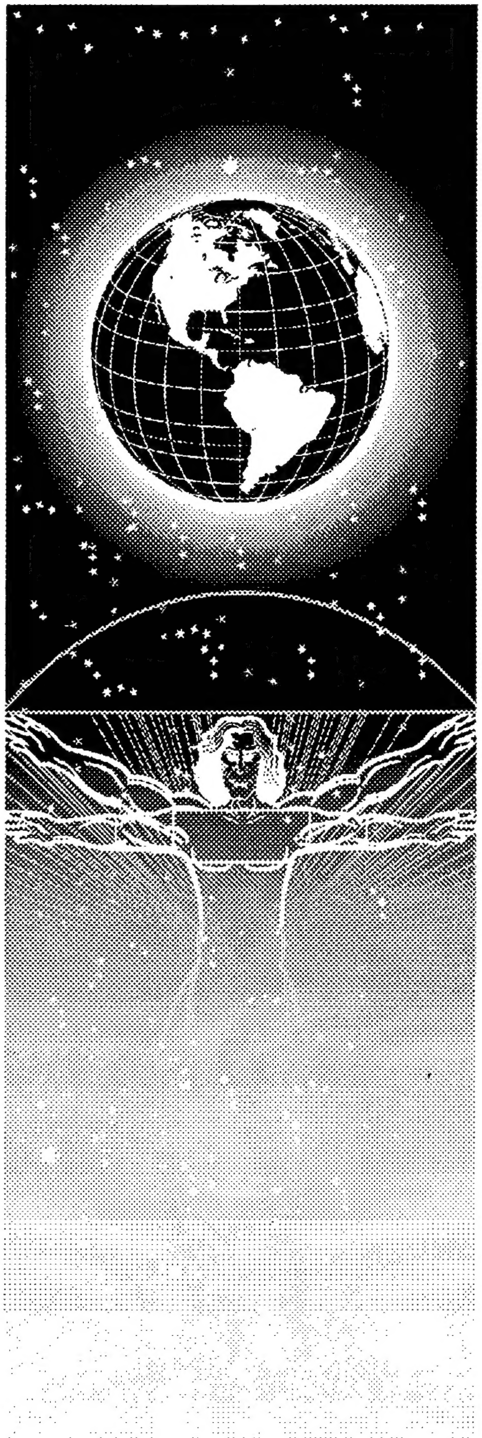
AL/HR-TP-1997-0051



UNITED STATES AIR FORCE
ARMSTRONG LABORATORY

Automated Support for Maintenance Technical Manuals

Edgar Sanchez
Steve Winning

MCDONNELL DOUGLAS AEROSPACE
MC 0343067, P.O. Box 516
St Louis, MO 63166

Edward S. Boyle

HUMAN RESOURCES DIRECTORATE
Logistics Research Division
2698 G Street
Wright-Patterson Air Force Base, Ohio 45433 7604

October 1997

Approved for public release; distribution is unlimited

Human Resources Directorate
Logistics Research Division
2698 G Street
Wright-Patterson AFB OH
45433-7604

NOTICES

When Government drawings, specifications, or other data are used for any purpose other than in connection with a definitely Government-related procurement, the United States Government incurs no responsibility or any obligation whatsoever. The fact that the Government may have formulated or in any way supplied the said drawings, specifications, or other data, is not to be regarded by implication, or otherwise in any manner construed, as licensing the holder, or any other person or corporation, or as conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

The Public Affairs Office has reviewed this paper and it is releasable to the National Technical Information Service, where it will be available to the general public, including foreign nationals.

This paper has been reviewed and is approved for publication.

Edward S. Boyle

EDWARD S. BOYLE
Program Manager

LOUIS M. JOHNSON, LT COL, USAF
Acting Chief, Logistics Research Division

PREFACE

This work was funded under Work Unit 2950-0054. Special thanks go to Chuck McMahon, formerly of the Logistics Research Division, for implementing and managing this project and for contributing his special expertise.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
October 1997

3. REPORT TYPE AND DATES COVERED
Final - Technical Paper

4. TITLE AND SUBTITLE
Automated Support for Maintenance Technical Manuals

5. FUNDING NUMBERS
C - F33657-92-D-2055
PE - 63106F
PR - 2950
TA - 00
WU - 54

6. AUTHOR(S)
Edgar Sanchez
Steve Winning
Edward Boyle

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
McDonnell Douglas Aerospace
MC 0343067 P.O. Box 516
St. Louis MO 63166

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Armstrong Laboratory
2698 G St.
Wright-Patterson Air Force Base OH 45433-6503

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AL/HR-TP-1997-0051

11. SUPPLEMENTARY NOTES
Armstrong Laboratory Monitor: Edward Boyle, AL/HRGA, DSN 785-5169

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The paper describes some aspects elements of technology support for automating the creation maintenance technical information in the form of Technical Orders. The viewpoint is that of a technical data "author" in a modern defense industry plant. The report includes a breakout of how this person currently allocates his time and effort to the various tasks he has to do, and it gives estimates on how automation support might chang his the workload. The repor points out pragmatic changes that might improve the quality and reduce of cost of maintenance technical data through automation support.

14. SUBJECT TERMS
technical orders; computer-aided design; computer-aided engineering; maintenance; automation; human form modeling

15. NUMBER OF PAGES
39

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLAS	UNCLAS	UNCLAS	SAR

Table Of Contents

List of Figures

List of Tables

1.0. INTRODUCTION

1.1. OBJECTIVES OF THE STUDY

1.1.1. Background

The production of maintenance Technical Orders (T.O.), Job Guides, Illustrated Parts Breakdown Manuals, and related publications account for a large share of the cost of weapon system acquisition.[1] Informal estimates put this cost as much as fifteen percent of the total acquisition cost for major new systems. But high cost isn't the only problem. T.O.'s are often delivered late to the field. And after they arrive, they are often found to be inaccurate or incomplete. Updating this documentation as weapon systems are modified is a continuous and cumbersome process.

Investments in data automation over the past decade, through CALS and related initiatives, have moved T.O. publications and other weapon system information from a bulky, paper past toward a streamlined, digital future. T.O.s have begun to appear in electronic, interactive formats. Legacy data is being converted to digital forms to make data management for weapon system support easier and less costly.

Despite these improvements, technology support for original technical data production remains relatively primitive. The T.O. "author" confronts an assortment of design and logistics information sources, a mix of automated and "manual" work tools, and a long list of other players who hold vital information and expertise. She must pool the contributions of design engineers, logistics and maintenance experts, draftsmen, and others to create maintenance technical data. This has never been an easy task, and modern "IETM" workstations, while helpful, have not reduced the cost or shortened the time line for original tech data production. Large productivity gains in the future can only come from automation support for the tech data development process in the first place.

1.1.2. Purpose

This paper describes some aspects of automation support used in the creation of maintenance information. It has a pragmatic outlook. The various advantages and drawbacks of automation are viewed from the perspective of actual maintenance technical writers in the defense industry. We attempt to define a set of automation needs without specifying the specific solutions. The objective is to establish a baseline for research and technology development to address practical problems in the real world.

---

[1] In this paper we use the terms Technical Orders, T.O., and tech data interchangeably. Job Guides, Illustrated Parts Breakdown Manuals, Troubleshooting Manuals, and other types of publications are included under these terms.

2.0 EXECUTIVE SUMMARY

Creation of technical manuals requires information assembled from a wide variety of sources. These include: (a) manufacturing design data to provide illustrations of various hardware assemblies; (b) diagnostic design data to provide troubleshooting methods and subsystem checkout procedures; and (c) logistics data to enumerate parts and materials. The main difficulty in reusing these sources of information in technical publications is that they are dispersed and not organized for the purpose. Rather than a lack of information, the problem has more to do with collecting and combining the information that already exists in useable formats. Figure 2.1 illustrates the central problem facing the technical order author.

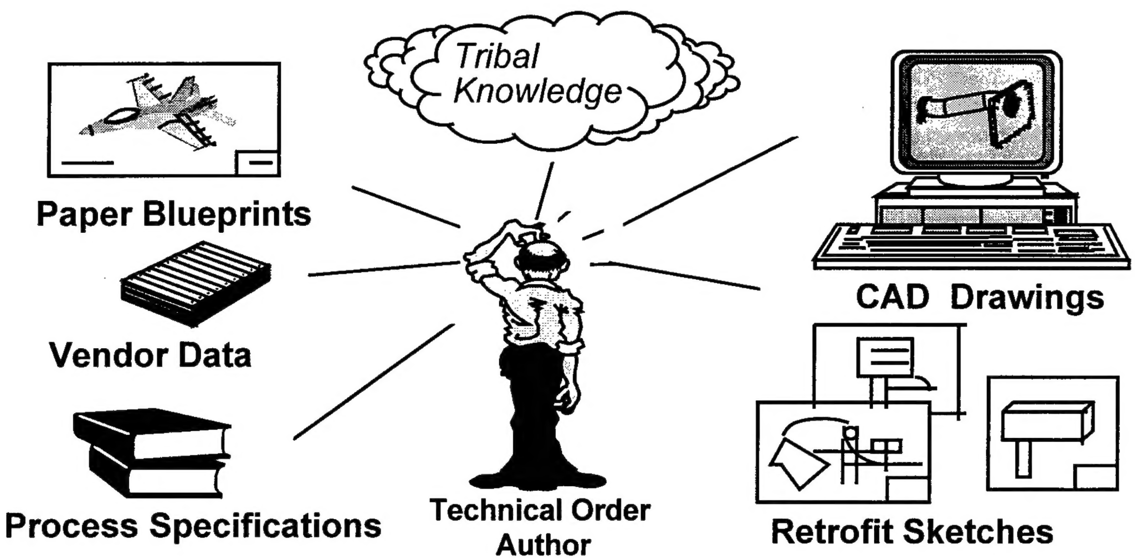


Figure 2.1. Multiple Sources of Information

Initiatives are under way to directly address the problem of organizing and integrating heterogeneous data. They can be summed up in the notion of a Product Data Manager (PDM), a system to handle all product-related information, including text, video, and multimedia files, in a common data repository. Engineering design analysis and simulation tools will use PDM as inputs. Results of these "virtual" simulations and analyses can be recorded as outputs captured by the PDM. The following two examples illustrate possible scenarios for collecting procedural and fault data, key data elements for Technical Orders.

Fault Data. The following example illustrates one possible scenario for collecting testing, and troubleshooting data for an aircraft fuel system. A fuel system designer creates an initial model of his system in Computer Aided Design (CAD) or other design aids. When

an initial system configuration has been achieved the design data will be stored in a database where it can be accessed by other tools. The designer (or another engineer) would then analyze system performance using Computer Aided Engineering (CAE) simulation tools. Based on the results of that analysis, several iterations between the design and performance simulation tools may be performed. At the same time, diagnostic and reliability tools can use the data obtained from the CAE tools (describing system connectivity and component behavior) to perform reliability and diagnostic analyses. Once a stable system design configuration has been achieved, the diagnostic predictive baseline can be stored in the diagnostic database. Once stored, further diagnostic development and failure modes analyses can proceed. Upon completion, the diagnostic process and failure modes and effects analysis, will also be stored in the diagnostic database. This data can then be used by an authoring tool to aid the author in the preparation of T.O. Test Tasks and Outcomes, Faults and Rectifications. This is the data that is the most difficult (and costly) to author, review, and maintain.

Procedural Data. The following example illustrates one possible scenario for collecting procedural data (removal, installation and parts data). Using the same CAD data developed in the above scenario, the design engineer creates an initial model of his system in CAD. Before significant investments are made for tooling or equipment, the manufacturing engineer performs an analysis of the impacts to manufacturing by simulating the manufacturing process, using Virtual Manufacturing (VM) simulation and modeling tools. Based on the results of that analysis, several iterations between the design and VM simulation tools may be performed. Once a stable system design configuration has been achieved, the same VM tools could be used to provide the T.O. author with a graphical interface for the development of assemble/disassembly sequences and procedures.

The technical path for automation support of T.O.s should include tools to access and combine requisite data from the design, manufacturing, and diagnostic databases in formats appropriate for the "authoring" task.

2.1. COST AVOIDANCE

The figures below are based on a typical aircraft organizational level T.O. library. We estimate that automation support of the types of tools described in this document could yield a T.O. cost saving on the order of 35 to 40 percent over the life cycle of typical weapon systems. This assumes that all engineering data is in the proper format to begin with (e.g., CAD models in solids, all systems modeled in Computer Aided Manufacturing tools, PDM in place at the component level).

2.1.1. <u>Locating and Tracking Data</u>

We estimate that about twenty-six percent of an author's time is spent locating and tracking the data required to produce T.O.s. (See Figure 2.2.) Once all the data required is located and the procedures are written, the T.O. content must be monitored for design

changes. A working Product Data Manager might save as much as 50 percent of this effort.

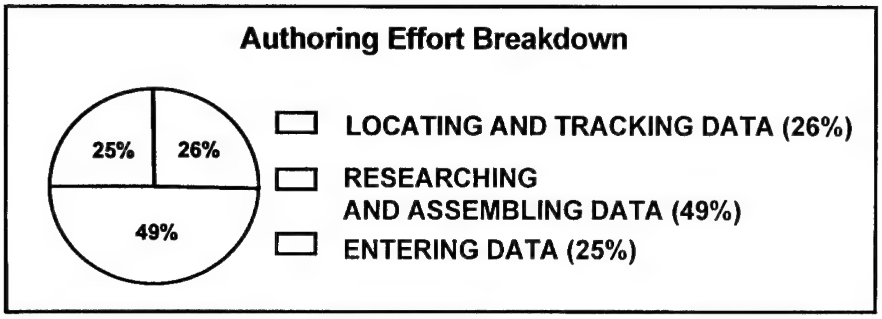


Figure 2.2. Breakdown Of Typical Authoring Effort

2.1.2. <u>Researching and Assembling Data</u>

Researching the data from the various sources and writing the procedures consumes about 49 percent of the author's time. Assembling this data from the various sources and presenting it to the author in a logical format could reduce this effort by about 15 to 25 percent, depending on the type of data being authored. See Figure 2.3. for average breakdown of T.O. data.

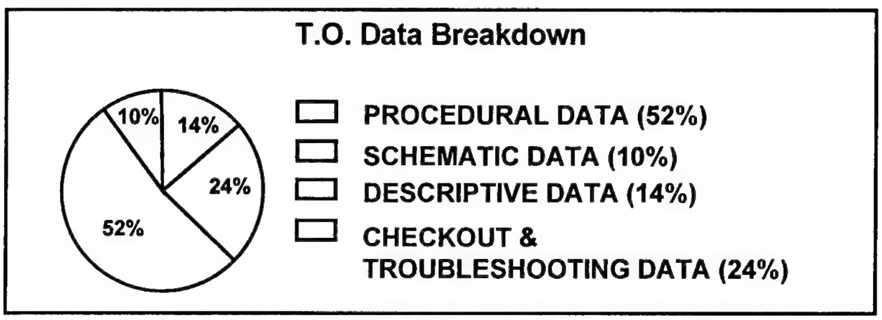


Figure 2.3. Typical Breakdown Of T.O. Data

2.1.2.1. Procedural Data

Authoring procedural data (e.g., removal and installation of components) involves generating text, graphics, and associated parts information required to perform the task. Tools that would allow the author to graphically simulate the procedure while automatically linking the text to the graphic and the parts data could substantially reduce the time needed to create maintenance procedure documentation.

2.1.2.2. Schematic Data

The time required to generate schematics could be reduced by about 20 percent if authored in a "connectivity" based system. The system would use the engineering wiring database for physical connectivity and the software connectivity from engineering CASE tools.

2.1.2.3. Testing And Troubleshooting Data

By using the data derived from engineering CAE and reliability analysis tools, the authoring of testing and troubleshooting data could be reduced by as much as 20 to 25 percent. Data accuracy could also be improved.

2.1.3. Entering Data

The process of manually keying the data into the authoring system consumes about 25 percent of the author's time. It is likely that some degree of manual labor will be required no matter how automation support for T.O. creation evolves. But the nature of the "authoring" task will dramatically change to emphasize consistency and other quality checking elements of production rather than original creation of text and graphical material.

2.2. REDUCING TIME LAG

Automation will reduce lag time in the area of design data location, extraction, and the insertion of that data into a T.O. Refer to Cost Avoidance in this section for reduction percentages.

Automation will provide the author with the greatest time saving in the areas of locating and tracking engineering design data. Automation concepts that use Product Data Management will provide access to all relevant data required by the author from one source. The availability of the data to the author immediately after engineering release also helps to reduce the time lag.

2.3. QUALITY AND ACCURACY

Automation impacts the quality and accuracy of T.O. products in different ways. Quality deals more with the completeness of the data and compliance with contract specifications Accuracy deals with the technical correctness of the data.

Quality assurance will demand time and effort regardless of what types of automation support T.O. creation. Yet it seems likely that some of the tasks involved in quality control can themselves be automated. Automatic word processing programs include spell checking and grammar flagging. Advanced T.O. generation systems could include analogous tools for evaluating wiring diagrams/schematics, verifying task step logic, and so on.

2.4. LEGACY DATA

Various types of engineering data for previous systems can be recruited for maintenance T.O. documents for new systems. Legacy design engineering data exists in the form of paper or electronic media. Existing tools that convert paper documents to electronic media using semantic and graphic recognition. Converting the heterogeneous legacy data into a format compatible with engineering tools (e.g., CAD models in solids, virtual manufacturing tools, computer-aided engineering tools) is time consuming and costly. Yet not populating the engineering tools with the legacy data would leave holes in the engineering data model. This would require additional automation tools to work around the problem. These additional tools would require a considerable amount of authoring time to transfer the disparate data elements into a T.O..

2.5. TECHNOLOGY REQUIREMENTS

2.5.1. Current State

Engineering automation tools provide a means of collecting the data needed to develop T.O.s. However, these tools have not yet been fully tested in the context of T.O. production. A pacing problem is the apparent lack of data exchange standards that would assure data integrity between different analysis applications. In addition, most of the currently available tools do not include data managers capable of tracking aircraft configuration changes. This is especially troublesome, since configuration changes affecting maintenance occur throughout the life cycle of aircraft systems, not just during original design.

2.5.2. Steps to Reach the Future State

The use of a Product Data Manager is probably the most significant step in reaching the goal of automatically deriving data from engineering tools for use in a T.O. The PDM would track all part hierarchy and effectivity information and maintain the relationships of engineering database files. The continued development of data exchange standards for functional simulation tools is required to data exchange between the engineering CAE/CASE tools. As noted, this is a problem of unstable or loose standards which allow flexibility in tool design, but hinder exchange of data between tools. The lack of data exchange standards limits the potential pay back from investments in automation tools.

3.0. TECHNICAL ORDER AUTHORING REQUIREMENTS

3.1. TECHNICAL ORDER CONTENT STRUCTURE

The structure of modern T.O.s is based on a functional system breakdown. Each system contains: descriptive information, part information, fault information, and task information.

3.1.1. Descriptive Information

Defines general purpose, non-procedural, narrative information such as theory of operation or physical descriptions of a system.

3.1.2. Part Information

Describes the maintainer's view of the part by identifying its relative position in the aircraft system/subsystem hierarchy. Part information contains supply system data; equivalent parts, sub-parts, part connections, and attachments with larger assemblies.

3.1.3. Fault Information

Defines all of the tests, faults, and rectifications associated with the system. Tests evoke tasks that identify how to perform the test, and outcomes that define the discrepancies found during the test. The outcomes have expressions which when evaluated, identify either a fault state for dynamic fault isolation; or a fault or test in a static fault structure.

Fault isolation data is provided by a troubleshooting tree where the maintainer is directed down a prescribed isolation and maintenance path to correct the problem. The maintainer will typically begin with a test which will lead him to a fault. The rectification for that fault is then displayed. A verification test is then called for.

3.1.4. Task Information

A maintenance task is a set of directed steps that together make up a logical work sequence. It is common to describe this work as either corrective (i.e., fix something) or preventive (i.e., avoid something breaking). These tasks are documented with simplified text, line art, tables, and references. The procedures are described in step-by-step sequence, generally using action words (e.g., remove, check, tighten) against objects (e.g., bolt, panel, nozzle). Warnings and cautions are interspersed. Required support equipment and tools are always specified. The task is illustrated through various types of line drawings, schematics, and other visual aids.

4.0. EXISTING INFRASTRUCTURE AND PROCESS (OVERVIEW)

4.1. RESEARCH

We estimate that about 75 percent of a T.O. author's time is spent locating, tracking, and researching system data. This process extends over the entire development cycle. Through research, the author collects and evaluates information to gain a comprehensive knowledge of the component or system. This includes its operating principles, use, materials, and maintenance requirements.

The amount of data available to the author depends on the developmental state of the component. During early development, the author will be limited to information sources such as:

Design specifications	Models
Design data books	Mock ups
Engineering design sketches	Personal working relationships with designers

As development progresses through production, delivery, and use of the equipment, research for the T.O. expands into areas such as:

Engineering drawings	Time compliance technical orders
Engineering orders	Publication change requests
Engineering change proposals	Field service trouble reports
Vendor data	Government furnished data

4.2. SOURCES OF DATA

As multiple legacy systems are used to design, analyze, and manufacture a product throughout the product life cycle, different pieces of product data are created by a variety of tools (See Figure 4.1). These data are stored on paper or in files or databases which reside on multiple electronic media.

The difficulty of collecting source data is sometimes exacerbated by the wide variety of packaging formats. Paper and diskettes, mircofiche and CD-ROM, engineering reports and specifications; the real world shows a disconcerting mix of source data. Locating and accessing source data is a time consuming problem. Indeed, it can take as much time to merely assemble the required data as it does to generate the T.O. products which depend on it.

Once the source data is accummulated, the T.O. author must establish configuration control process for the data. All data used must be systematically re-accessed and

evaluated to ensure that the most recent data are incorporated into the maintenance manuals. This process is exercised throughout the product life cycle.

The following data sources of data are used in the development of T.O. data. The data is broken down by the major categories of information provided in a T.O. (e.g., DESCRIPTIVE, PROCEDURAL, FAULT, PART)

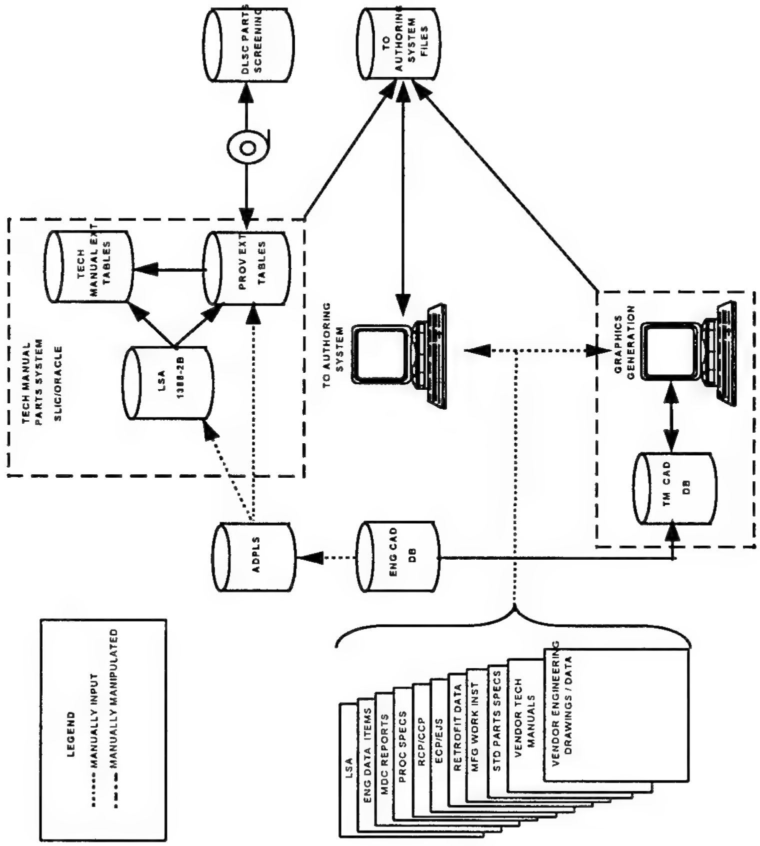


Figure 4.1 Sources of Data

5.0. <u>FUTURE INFRASTRUCTURE AND PROCESS (OVERVIEW)</u>

5.1. DESIGN TOOL OVERVIEW

5.1.1. <u>Computer Aided Engineering (CAE)</u>

Figure 5.1 illustrates how design engineers use CAE tools. These tools enable the designer to select component models from a library and connect them to represent the functional design of the system. In the conceptual phase of design, these models are often based on similar existing components that provide the same (or similar) functions. As the

design matures, new components may have to be designed and modeled for the component library. Included in the component models are parameters about the component, such as pressure, flow rates, power requirements, failure modes, inputs, outputs, and so on. Once the system model is developed from the component models and their connectivity, some CAE tools allow simulation of the system functions. This same simulation also provides logistics analysts the ability to simulate failures of individual components and to determine their effects. These failure modes and effects analyses (FMEA) define the maintenance tasks that will be required. The maintenance task analysis data (manpower, tools, and support equipment, etc.) are ultimately tied to this FMEA.

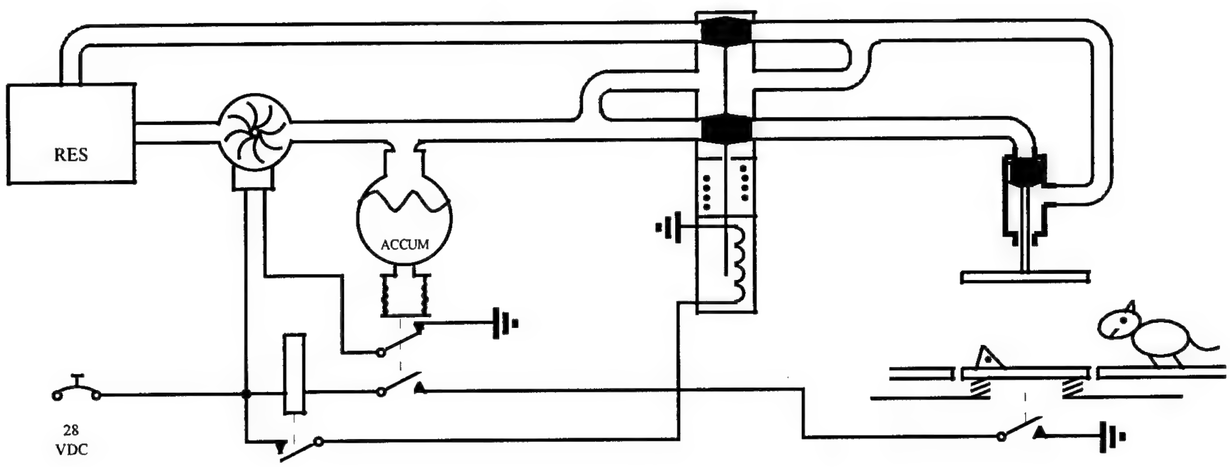


Figure 5.1 Example of CAE Tool Display

Maintenance task analysis data can also be produced using a simulation approach early in design development, before hardware is fabricated. We foresee a number of CAD-based visualization technologies supporting this capability. One of these, human form modeling, can provide early identification of maintenance problems and highlight possible solutions for CAD engineers. For example, if a component to be removed is shown through 3-D CAD animation to be obstructed by other components, it might be relocated or perhaps redesigned to assure ease of removal. If a simulated maintenance person in the CAD environment cannot easily reach a component, we can suggest possible work arounds for the problem. Maintenance procedures verified and perhaps improved with this sort of simulation could then be passed to the authoring process for incorporation into maintenance T.O.s. (See also Section 8 below.)

5.1.2. Computer Aided Design (CAD)

Once the hardware functional design is approved, the physical part of the design process begins. The system components are either procured or manufactured based upon the design requirements. CAD tools are used to assist in these efforts (See Figure 5.2).

These tools define the assembly of the various components into the final product. The data contained in these systems are the appearance of the part, location, part number, and any parts required to attach one part to another. As indicated above, CAE siimulation and virtual reality tools are being integrated with the CAD systems to test the physical design component interference and maintainability prior to physical design approval. These physical models have the potential to eliminate the physical mockups that were built prior to production. Most new products in aerospace, automotive, and related manufacturing industries are being designed and engineered with CAD/CAE technologies. This automation format is probably the most important development for T.O. generation in the future.

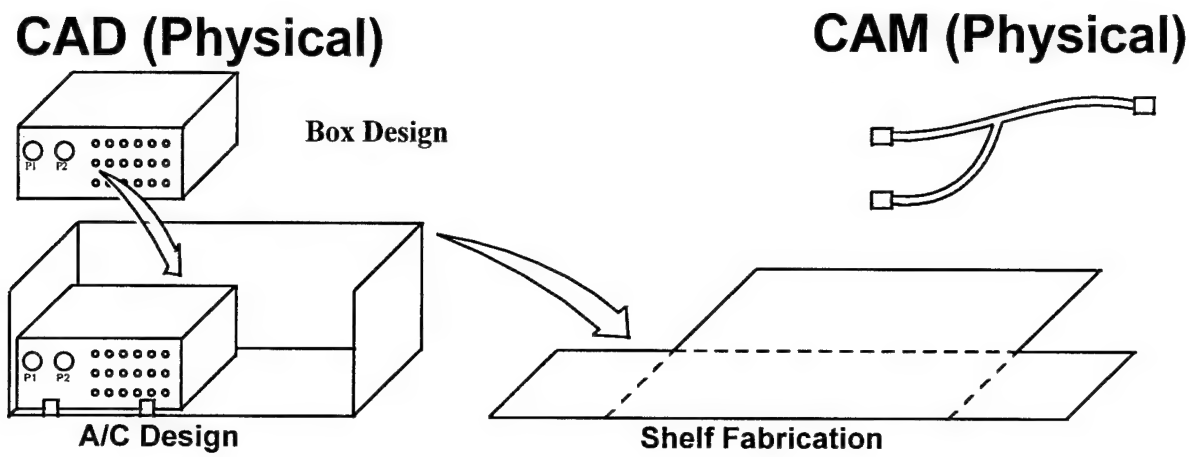


Figure 5.2 CAD Tool Example

5.1.3. Computer Assisted Software Engineering (CASE)

Just as CAE tools are being developed to assist in the development of the functional design for hardware components, CASE tools are being developed to assist in the development and documentation of computer software (See Figure 5.3). These tools enable the software design engineer to graphically depict the software flow, to test the software through simulation and to generate the code using automatic code generation tools. These tools assist to shorten the software development time. At the organizational level of maintenance, the operation of the weapon system is more dependent upon software than the hardware of the computers. The software function must be integrated with the hardware function to determine the overall functional operation. The integration of the software and hardware will determine how the system operates and the extent to which the system can monitor and record diagnostic information.

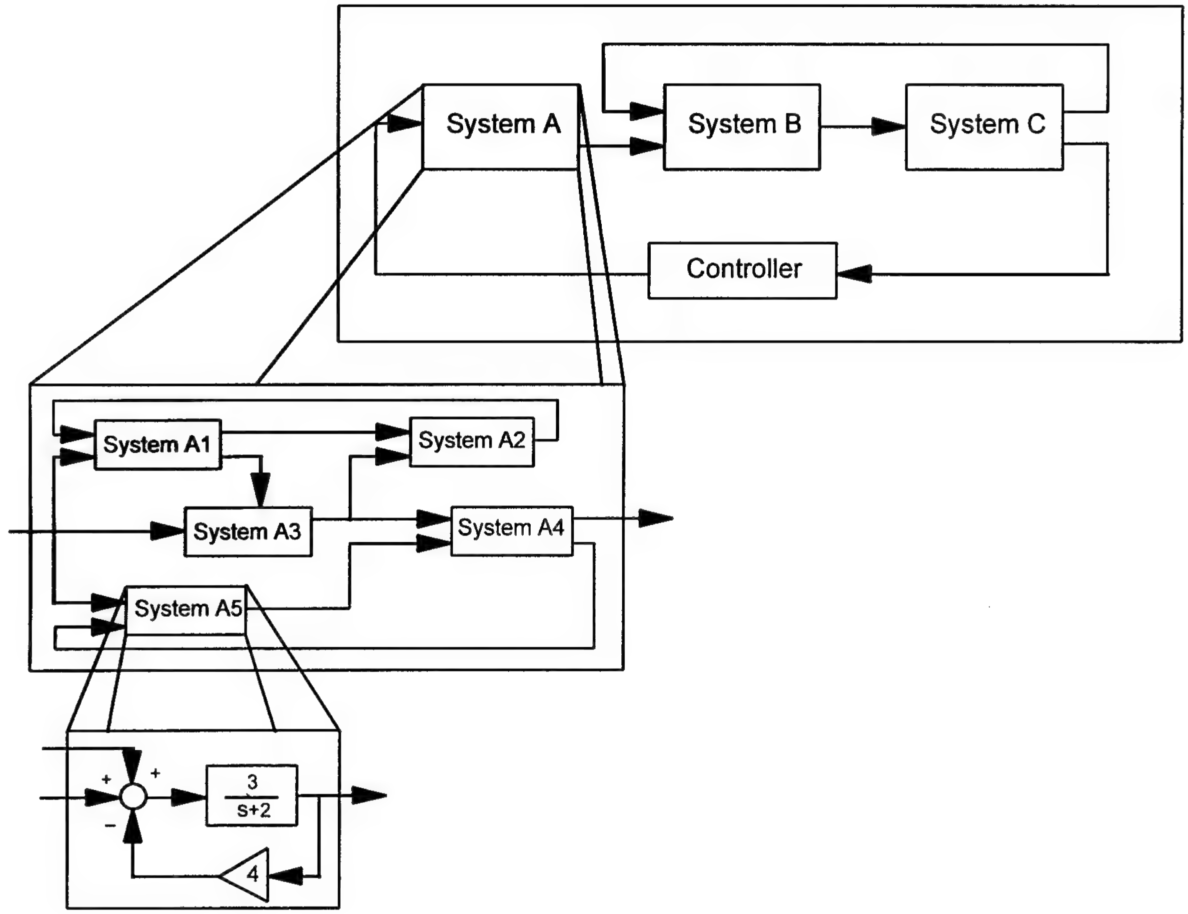


Figure 5.3 CASE Tool Example

5.2 SOURCE TO DATA MAPPING

5.2.1. CAE to Technical Order Data Elements

Computer Aided Engineering and Computer Aided Software Engineering tools are the source of functional design information to populate the following T.O. data elements:

- System Description
- Functional Operation
- Tests
- Fault Isolation
- Schematics

5.2.1.1. System Description

The component parameters contained in the component library of the CAE tool; such as pressure, flow rates, power requirements, failure modes, inputs, outputs, etc. have the

potential of providing inputs for the descriptive information elements of the T.O.. These could be used to help describe the functional characteristics of each component within the system.

5.2.1.2. Functional Operation

The connectivity defined in the CAE tools, along with the parameters associated with the components, define how the components interact with one another to provide system functionality. The model representation of the system can be used as the source for the development of the operational description.

5.2.1.3. Test Information and Fault Isolation

Based upon the functional operation depicted in the design models and the simulation capabilities, the CAE tools are also the source for test information and the resulting outcome expressions. These are derived from the failure modes and effect analysis part of the design process. Based upon the Failure Modes and Effect Analysis (FMEA), the appropriate maintenance task or test is determined. These are inputs into the dynamic or static fault structure of the T.O. The fault structure can be derived based upon the connectivity (dependencies) linked to the diagnostics design of the system.

Fault data contains all tests, faults, and rectifications for a system. A test is a diagnostic procedure designed to help the maintainer troubleshoot weapon system problems. Tests will drive the maintainer to a fault and associated rectification.

The Computer Aided Engineering (CAE) tools enable design engineers to design and simulate aircraft system operation (See Figure 5.4). These tools are being enhanced to provide FMEA authoring within the tool.

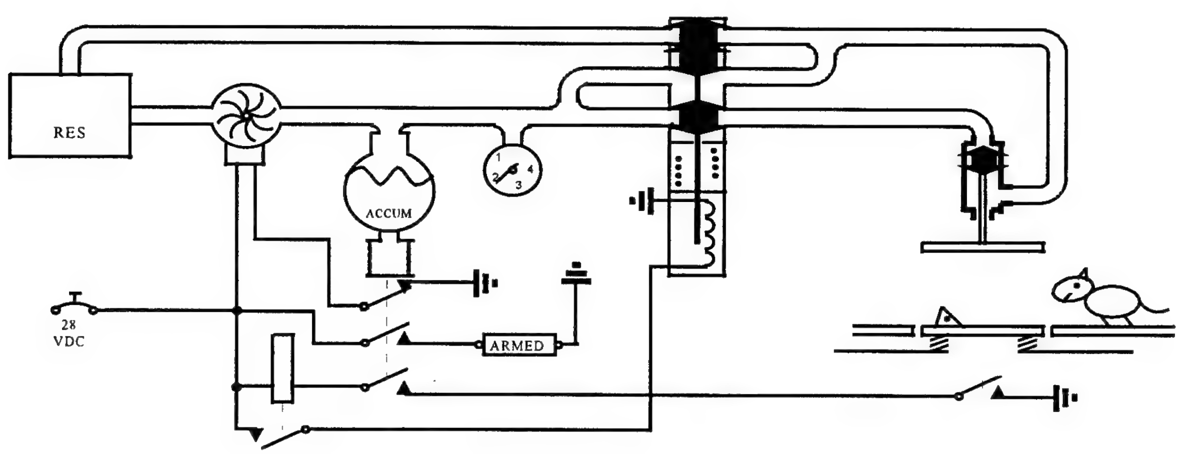


Figure 5.4. Example of CAE Display

The tool allows the engineer to fail a component and observe the overall effects on the system. The resulting FMEA data (Table 5.1) provides the information required to support the generation of fault isolation data to be used in the T.O.

Table 5.1. FMEA Data Needed to Generate Fault Isolation

LRU	SRU	Failure Mode	Failure Effects LRU	Failure Effects SYS
Pump	Motor	Open		Press < 1800 Light Off Trap Will Not Trip/Reset
Pump	Motor	Closed		Press > 1800 Light On Pump operates Continuously
Relay Coil	Coil	Open		Press > 1800 Light Off Trap will Not Trip
Relay	Coil	Closed		Press < 1800 Light On Trap will Not Reset
Valve	Coil	Open		Press > 1800 Light Off Trap will Not Trip
Valve	Coil	Closed		Press > 1800 Light On Trap will Not Reset
Wiring - Splice to Relay Coil		Open		Press > 1800 Light Off Trap will Not Trip
Wiring - Panel Splice to Relay Sw		Open		Press > 1800 Light Off Trap will Not Trip

Combining all like failure effects of each component in the system will provide a list of all Line Replaceable Units (LRU's) whose failure would cause the failure effect. (See Table 5.2). These data, when linked to Logistic Support Analysis (LSA) fault data, can provide additional information such as access times and maintenance levels for repair/replacement.

Table 5.2. Fault Data from FMEA and LSA

Fault Description	Fault	Fail Mode	MTBF	ACCESS
Press > 1800	Pump Motor	S-Gnd		
Light On	Wiring			
Pump Operates Continually	Pump To Accum Sw	S-Gnd		
Press > 1800	**Relay**	**Open**		
Light On	**Accum Sw**	**Open**		
Trap Will Not Trip	**Valve**	**Open**		
	Trip Sw	**Open**		
	Wiring			
	Splice To Relay Coil	**Open**		
	Relay Sw to Valve	**Open**		
	Panel Splice To Relay Sw	**Open**		
	Accum Sw To Trip Sw	**Open**		
	Relay To Accum	**Open**		
	Trip Sw To Ground	**Open**		
	Valve To Ground	**Open**		
Press > 1800	Relay	Closed		
Light On	Wiring			
Trap Trips Pwr On	Relay To Valve	S-Pwr		
Resets Pwr Off				

Using the fault, TRAP WILL NOT TRIP, PRESS > 1800 and LIGHT ON from Table 5.2, the tool could provide a list of all components that could cause the fault, in most probable order, with access times identified for reference. The tool could also display the affected area of interest for reference in developing the troubleshooting procedure

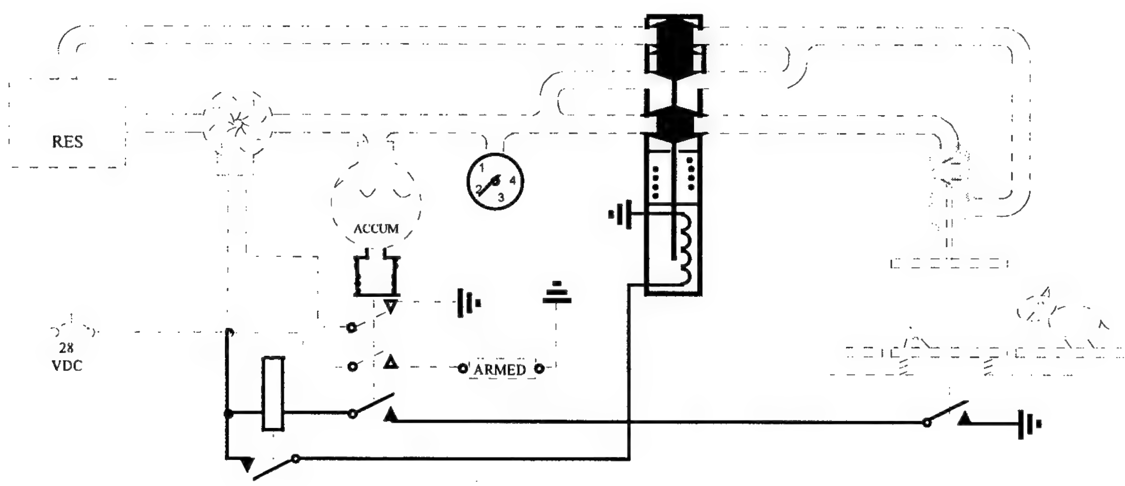


Figure 5.5. Example Of Area Of Interest Display

The level of detail for the area of interest (Figure 5.5) could then be expanded to provide greater detail of a specific area. This could be done as the author generates the individual tests required to isolate the failed part. (Figure 5.6)

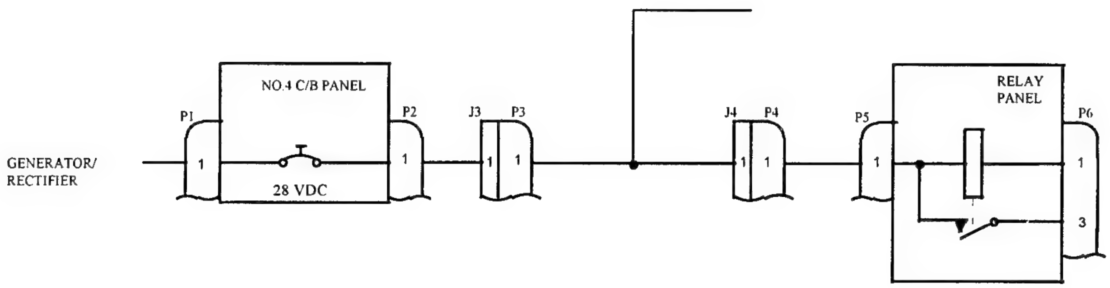


Figure 5.6. Expanded Level of Detail Supporting Individual Tests

To allow all faults to be grouped by failure effects, fault description must be consistent (i.e., trap fails to trip vs. trap does not operate vs. trap does not actuate). Fault description should be auto generated by the FMEA tool whenever possible

Fault description must be provided by reportable/observable indications (i.e., Pilot Observable, Data Storage Unit, Maintainer Observable, etc.)

5.2.1.4. Schematics

The transition of design communities to CAE and CASE tools provides the Technical Publication community with the ability to import design/engineering data into a T.O. authoring system. These tools contain the connectivity and functionality of an entire system. In essence, these tools contain the same technical data as schematics delivered in a paper form today. A separate schematic tool could extract the necessary design data, and import that data into an T.O. authoring system. The schematic tool could then either automatically, or with some manual authoring, generate a T.O. schematic.

5.2.2. <u>CAD To Technical Order Data Elements</u>

Computer Aided Design tools could become the source for physical design information to populate the following T.O. data elements:

- Graphic (model) Representation
- Physical Description
- Physical Operation (Mechanical Controls)
- Procedural Tasks (Remove, Install, Adjust)
- Part Information

5.2.2.1. Graphic (Model) Representation

The graphic model of the component, whether developed by the supplier or by the prime contractor, depicts the physical aspects of design and can be linked as applicable from a multitude of T.O. data elements. There are three basic types of graphics models representing the component;

- Locator graphics which show the location of a part within the system
- Detailed graphics which show the component from different views for descriptive purposes
- Parts breakdown graphics that depict the parts which connect to or attach the component to other components.

5.2.2.2. Defining the Graphic Parameters.

Automated generation of graphics would require development of software to assemble and display graphics matching the defined parameters (graphics parts list and viewpoint) (See Figure 5.7). The objective would be to use part geometry data from design databases to create the graphic image rather than duplicate part geometry in a separate file. The output would be a displayed graphic and/or Computer Graphics Metafile (CGM).

If the part geometry is modeled in solids, it is feasible that the assembled graphic would require no manual clean-up, such as removal of hidden lines. The first step in generating a graphic is to define its parameters. These parameters will define viewpoint and the parts to be included (the graphic parts list). Viewpoint can be made straightforward by allowing a predetermined set of views, such as looking down and aft at right hand side. Generating the graphics parts list could be accomplished by several methods:

- Directly entering the list of desired parts.
- Using the parts structure database to generate the list by assembly numbers and effectivity.
- Using spatial data to list parts within defined aircraft coordinates.
- Once an initial list is generated it would be possible to further refine the list until the desired result is achieved.

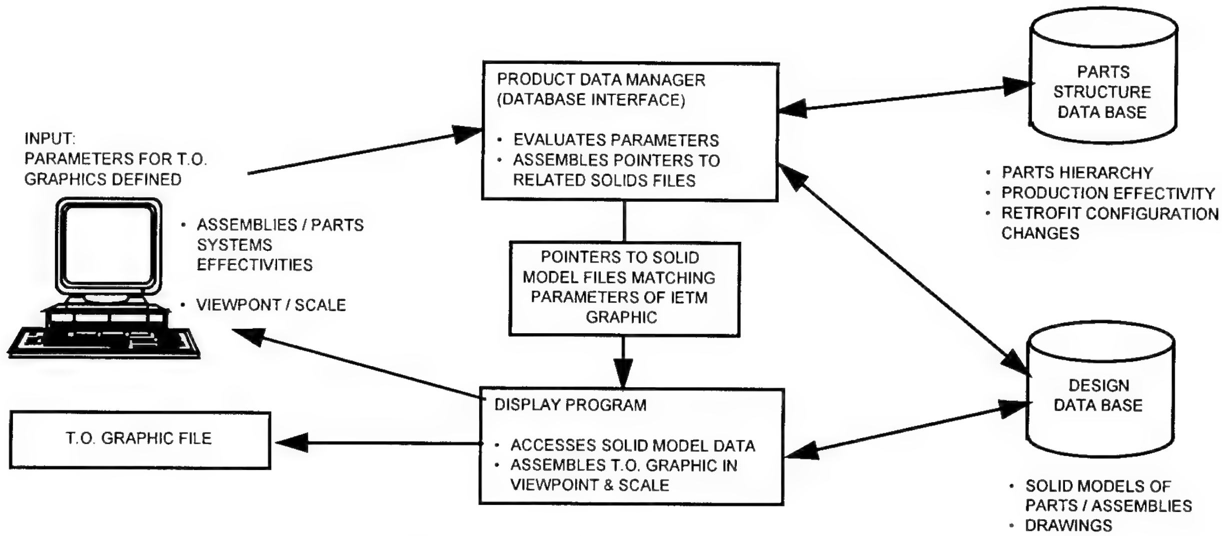


Figure 5.7. Graphic Generation

5.2.2.3. Physical Description

The detail graphic and the locator graphic can be used as a source to describe the physical location and appearance of the component as it applies to a specific weapon system.

5.2.2.4. Physical Operation

The Illustrated Parts Breakdown (IPB) type graphic, which shows the physical connectivity of one component to another, can be used to depict the mechanical operation of a system. Used in conjunction with virtual reality and model simulation tools, these graphics models become the source for the operational description of the system.

5.2.2.5. Procedural Tasks (Remove, Install, Adjust)

CAD systems have four data elements that are of interest in developing an outline of a procedural task: component identification, connecting parts, attaching parts, and interference identification. A tool could be developed to:

- Rotate the CAD models to the closest view for the task (i.e., looking inboard, outboard, forward, or aft).
- Determine if the component can be moved in the direction of the point of view. If it can't, is interference caused by an access door part? If it can, then add step "Open/remove door." If it can't, try various angles to eliminate interference. If interference no longer exists, add as the last step "Rotate component __ degrees and remove." If interference still exists, add Required Condition "Remove component ?" If interference no longer exists or never existed, then check for connecting and attaching parts. If connecting parts, add step(s) "Disconnect ?". If attaching parts, then add step(s) "Remove/Loosen ?". After all connecting and attaching parts are addressed, add step "Remove ?"

5.2.2.6. Parts Information

Parts data provides the information required to identify and order all repair parts. As parts are identified by design engineering, they are logged in the PDM identifying parts usage. Once in the product data manager and released, the Provisioning Group researches the part for equivalents, assigns recommended nomenclature, assigns Source Maintenance and Recoverability (SM&R) code, Commercial And Government Entity (CAGE) code, etc. and forwards to Defense Logistics Services Center (DLSC) for Screening. DLSC assigns the National Stock Number (NSN), approves/changes recommended nomenclature as required and returns the updated parts information to the contractor (See Figure 5.8).

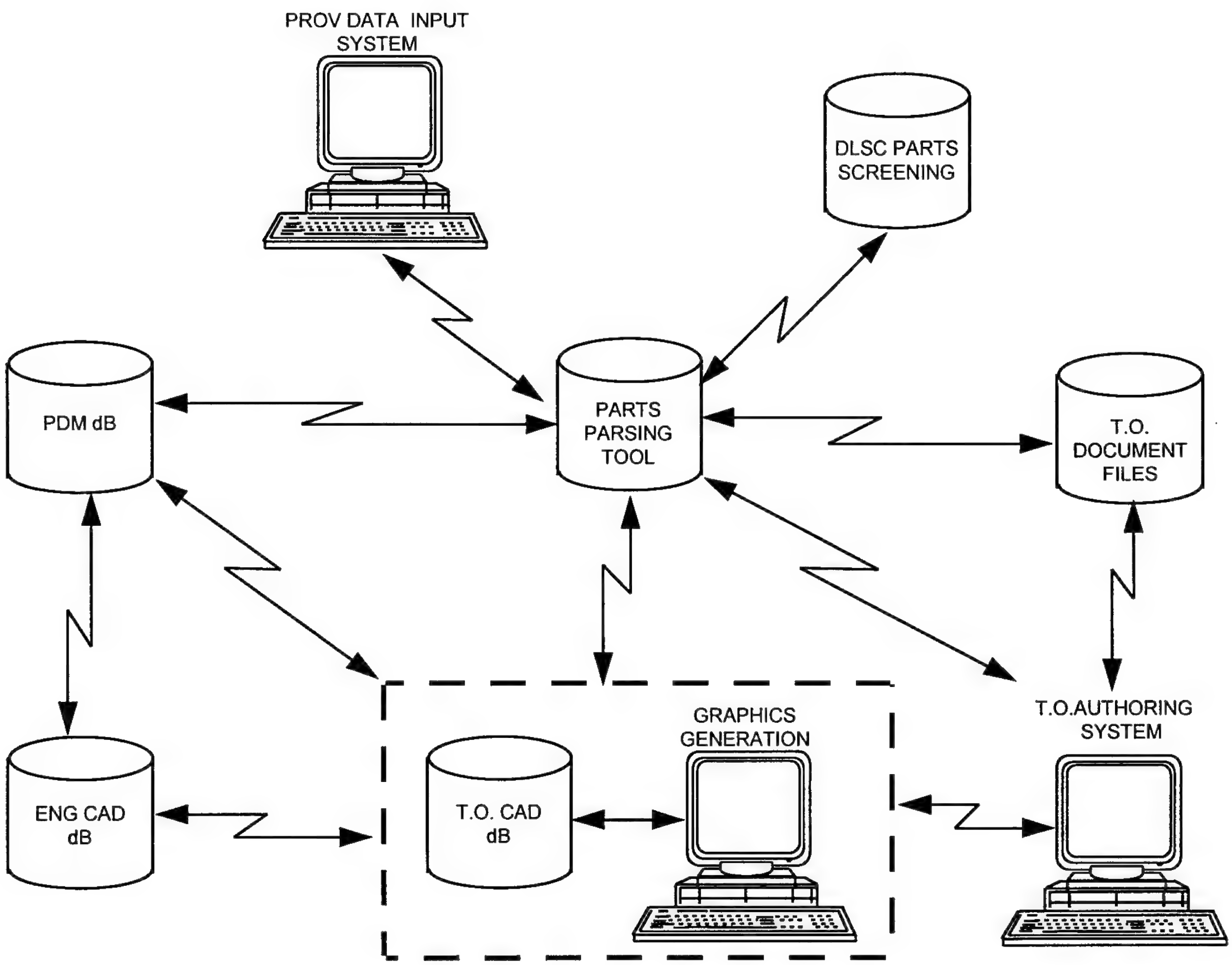


Figure 5.8. Parts Data Generation.

The job of the Product Data Manager is to maintain the relationships of database files. It would contain all part hierarchy and effectivity information. As a single source for production and post-production configuration management, the product data manager could feed automated generation of T.O. graphics and illustrated parts breakdowns. The T.O. author would pull up the engineering "build-to" package (paragraph 5.3.2.3). Modify the drawing in CAD if required and promote the drawing for use in T.O.s. The process of

promoting the drawing would create links to the PDM, extract all part geometry from the engineering CAD system, assign index numbers to part geometry, associate part information to the index numbers, and create a T.O. graphic file. The parser compares the part information to the existing T.O. data base. It then eliminates duplicate parts and sends all new parts to the provisioning parser to add required provisioning info (CAGE, SM&R, equivalent parts, etc.). The parser then moves the part data into the T.O. and updates the PDM with T.O. version data (See Figure 5.9).

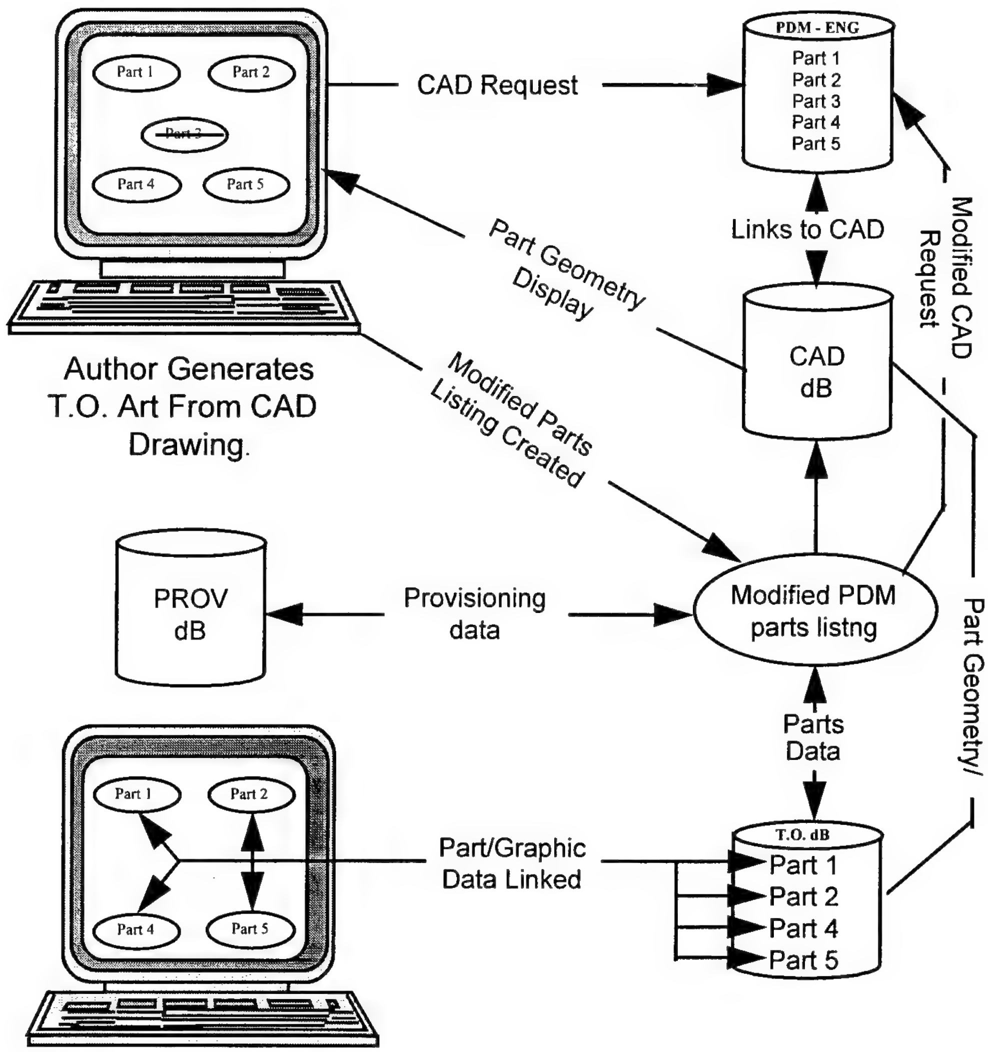


Figure 5.9. Parts and Graphic Linking

5.3. CONFIGURATION CONTROL

The manufacturing industry has made significant investments in information technologies (IT) to automate various processes in the product life cycle. These

investments are seen in the rapid growth of the computer-aided design, manufacturing, engineering, and computer-integrated manufacturing (CAD/CAM/CAE/CIM) market. The industry has been hampered by a phenomenon known as "islands of automation" characterized by:

- Maintenance of incompatible data definition formats. A number of translators are required to allow data files to be shared between different systems.

- The need to retain separate views of the product structure using engineering, manufacturing, and product support parts data (EBOM, MBOM, provisioning and illustrated parts breakdown).

- The rapid generation of large quantities of design data that makes manual control of these data extremely difficult.

As a result, the maintenance cost for legacy systems remains a major expenditure for a typical manufacturing company. Consequently, the focus must shift to managing the data sets generated by these tools.

In an attempt to tackle this effort, a new class of applications, called Product Data Managers (PDM) are required to allow configuration management of almost any type of data set. (See Figure 5.10) The PDM relates all of the data relevant to a particular product/part. It does this using a product viewpoint.

- Product Structure Configuration Management - Provides a set of functions to maintain various configurations of the product definition data: associating data sets to parts of a given assembly; traversing the Bill of Materials (BOM) through explosion or implosion; applying effectivity to parts of a given installation; creating virtual assemblies by instancing component geometry.

- Group Technology and Parts Library - Provides a set of functions to classify and group parts to increase accessibility and reusability: maintaining universal parts codes; maintaining standard component libraries.

- Data Conversion - Provides a set of functions to present the requested data to the user in proper format on the target device: automatically invoking the proper translator for data format translation; performing proper conversion in a multimedia environment.

- Program Management - Provides a set of functions to define the business processes and manage the project based on a given process: defining processes based on a standard process modeling methodology; maintaining Work Breakdown Structure (WBS) and networks; performing resource scheduling; monitoring project status.

- T.O. Authoring Support - Provides a set of functions to make product information readily available to support T.O. authoring; automatically generating the information by extracting raw data based on user specified criteria; and maintaining traceability.

Configuration control automates tedious bookkeeping tasks and helps authors develop T.O. data smoothly. Using a configuration control tool, authors can track each change to the source data and associate T.O. data with each change. It can ensure that authors are working with the most current source data and that they do not overwrite changes. The system can easily determine what T.O. data has been changed and why the change was made. This information is especially useful for audit purposes by providing detailed documentation for every change. In summary, configuration control for T.O. data is required to ensure that the source data used is the latest and most accurate data available. This is accomplished by providing:

- Providing visibility over the change process through change and difference reports,
- Ensuring authors are working with the most current version of code,
- Preventing data from moving to the next phase without completing all required approvals,
- Ensuring that concurrent changes to the same item are merged and prevent change regression,
- Allowing different functional groups to work on the same application in parallel
- Streamlining the release cycle,
- Allowing older releases to be maintained concurrent with a new release, and
- Eliminating unwanted changes by ensuring a single path by which changes can enter production.

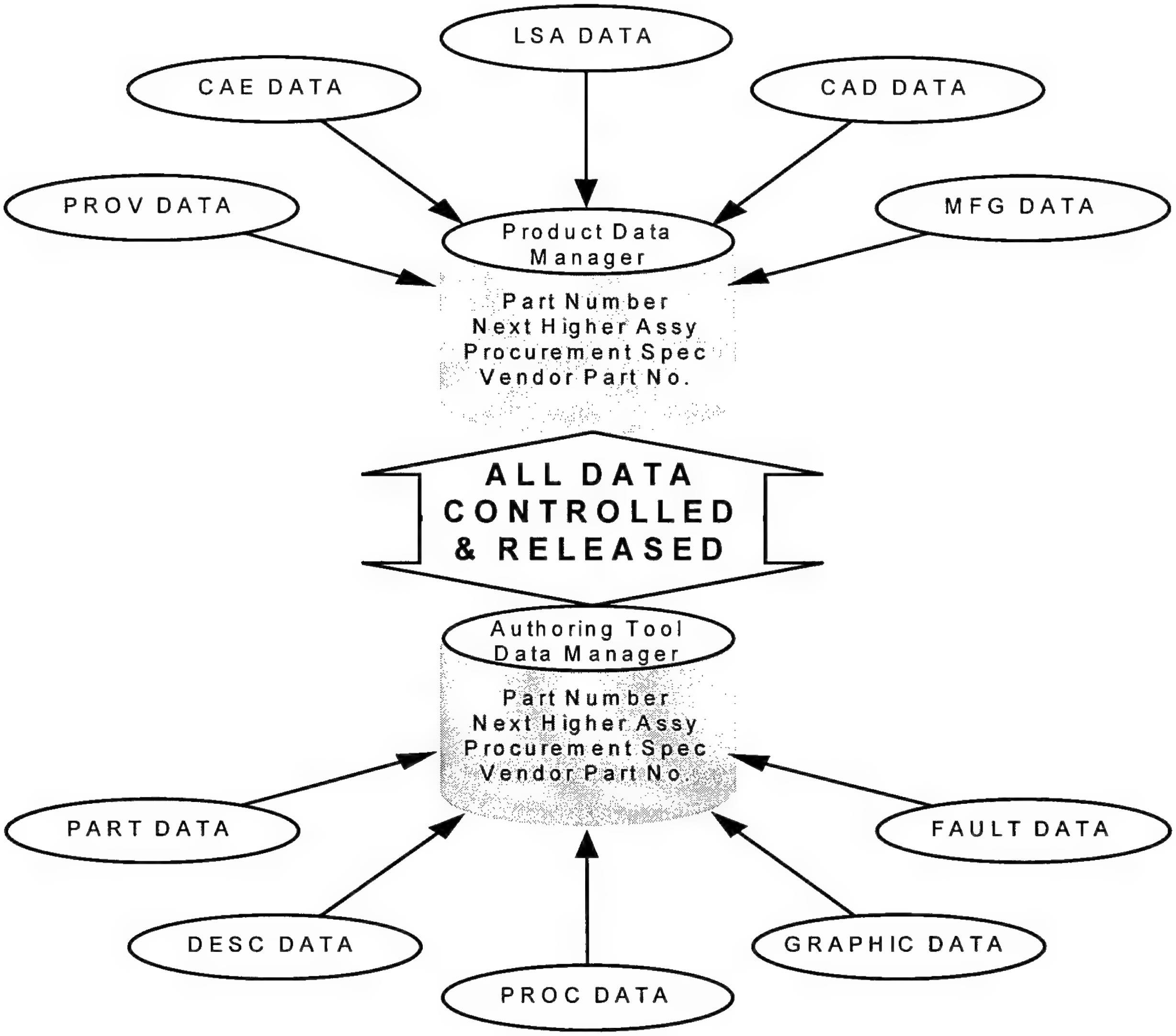


Figure 5.10. Control And Release Of Data.

6.0. ISSUES

6.1. COMPATIBILITY

Compatibility between different design tools presents a major obstacle for automation of T.O. processes. Better standards seem to be a prerequisite for progress.

6.2. CLASSIFIED, PROPRIETARY, AND COMPANY SENSITIVE DATA

Obtaining classified, proprietary and company sensitive data has been a problem in the past resulting in late delivery of the data to the field. A method of filtering this type of data contained in design models and tools needs to be developed to support automation concepts.

6.3. CONFIGURATION

Configuration control is also required for technical data automation. All configurations must be maintained, in a PDM, throughout the product life cycle. Most design engineering systems track or maintain only the configuration currently in production. Field modifications and retrofits must also be included to assure data integrity.

6.4. LEGACY DATA

The cost of converting engineering legacy data from paper or other electronic media to a format suitable for technical data automation is a continuing problem.

6.5. CONTRACTUAL APPROVAL

Engineering approval for contract changes to a weapon system occur long before publication approvals to incorporate those changes occur. Engineering is consistently working a multitude of contractual changes, with the possibility of each having different completion dates. Hence, automation tools for maintenance technical data must have the capability to filter out configuration changes that have been approved for engineering, but not approved for T.O. incorporation.

7.0. SKILLS REQUIREMENT EVALUATION

7.1. CURRENT PAPER BASED AUTHORING SKILLS REQUIRED

- Degree associated with aircraft maintenance
- Experience in aircraft maintenance
    - Weapons - Hands on
      - Avionics background
    - Avionics - Detailed avionics training
- Can read and understand schematics
- Blueprint reading
- Basic computer skills
- Knowledge of Air Force/Navy/Army maintenance levels of repair
- Communications skills, both verbal and written

7.2. AUTOMATED TECHNICAL ORDER - WITH AUTHORING REQUIRED

- Degree associated with aircraft maintenance
- Experience in aircraft maintenance
    - Weapons - Hands on
      - Avionics background
    - Avionics - Detailed avionics training
- Can read and understand schematics
- Blue print reading
- Basic computer skills
- Knowledge of Air Force/Navy/Army maintenance levels of repair
- Communications skills, both verbal and written
- Basic understanding of Database concepts
- Basic understanding of elementary computer programming constraints
- Paradigm shift of constructing instructions in an electronic media environment verses traditional document composition

7.3. AUTOMATED TECHNICAL ORDER - WITH NO AUTHORING REQUIRED

- Degree associated with aircraft maintenance
- Experience in aircraft maintenance
    - Weapons - Hands on
      - Avionics background
    - Avionics - Detailed avionics training
- Basic understanding of schematics
- Basic blueprint reading skills
- Basic computer skills
- Knowledge of Air Force/Navy/Army maintenance levels of repair
- Communications skills, both verbal and written

- Basic understanding of database concepts
- Basic understanding of elementary computer programming constraints
- Paradigm shift of constructing instructions in an electronic media environment verses traditional document composition

8.0. GOVERNMENT-FURNISHED SOFTWARE TOOLS

8.1. DESIGN EVALUATION FOR PERSONNEL, TRAINING, AND HUMAN FACTORS (DEPTH) SIMULATION – EVALUATION OF SOFTWARE

DEPTH is a software tool for visualizing and analyzing certain aspects of human/machine and human/workplace interaction during the early design process. The key feature of this CAD-oriented simulation tool is a human form model which replicates many of the physical capabilities of real persons. The human form model (derived from the Jack model of the University of Pennsylvania) can be made to interact with given design configurations to assess gross aspects of maintainability. The idea is to perform maintenance task analysis electronically during the early design phase in parallel with other sorts of engineering analysis. In DEPTH, simulated persons can be made to act out typical maintenance tasks directly on the CAD screen. When augmented with information about the physical limits of human performance and with information about the maintenance task, DEPTH simulation can yield task analysis information that has previously required hard mock-ups to obtain.

DEPTH is a research-based tool still under development by Armstrong Laboratory. Although there are many refinements and extensions still needed, the outlines of a tool for automated T.O. creation using DEPTH technology are in plain view. Many of the data elements specified for maintenance task analysis of military systems are also needed for T.O. development. Hence, extensions of DEPTH technology to support the T.O. automation problem are natural and valuable.

Probe studies indicate that the most difficult technical challenge seems to lie in the automatic generation of maintenance procedures (or task steps) from equipment definitions (or product data models) in the form of natural language. This language, generated from a technical domain known as computational linguistics, can be used both to create text for incorporation into a T.O. and to mechanize simulations of given maintenance tasks using human form modeling.

Another technical challenge lies in findings ways to augment CAD product models with information relevant to maintenance analysis. Currently, product models convey mainly geometric data. They need to contain part labels and related lexical “tags” to support automatic extraction of maintenance requirements and their documentation. Specifications and standards to accomplish this are slowly evolving in the form of STEP (Standard for the Exchange of Product Data) and PDES (Product Data Exchange using STEP).

A tool such as DEPTH, when integrated with a production CAD system, could provide a valuable tool in the area of maintainability. It would be valuable in the testing of a complex assembly during the design phase prior to manufacturing. However, developing these models for all replaceable components on a weapon system may not be cost effective. Many components are easily accessed and would not require analysis at a detailed level. If the above recommendations are incorporated into the DEPTH tool, besides auto generating the more complex tasks, a simplified authoring tool could be developed within DEPTH. This tool would utilize a subset of the DEPTH features allowing the author to graphically create these less complex tasks.

Configuration control is another area that requires examination. When importing solid models from CAD into simulation tools like DEPTH, configuration control is required to support updates and identify the various aircraft configurations. This information could be used to notify the T.O. author of changes required to the tasks/graphics developed using the DEPTH tool.

ACRONYM LIST

ATOG	Automated Technical Order Generation
BOM	Bill of Materials
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAGE	Commercial And Government Entity
CAM	Computer Aided Manufacturing
CASE	Computer Aided Software Engineering
CGM	Computer Graphics Metafile
CIM	Computer-Integrated Manufacturing
DEPTH	Design Evaluation for Personnel, Training, and Human Factors
DLSC	Defense Logistics Services Center
EBOM	Engineering Bill of Materials
FMEA	Failure Mode and Effect Analysis
IPB	Illustrated Parts Breakdown
IT	Information Technologies
LRU	Line Replaceable Unit
LSA	Logistic Support Analysis
MBOM	Manufacturing Bill of Materials
NSN	National Stock Number
PDM	Product Data Manager
SM&R	Source Maintainability and Recovery
T.O.	Technical Order
VM	Virtual Manufacturing
WBS	Work Breakdown Structure

APPENDIX A

AUTHORING EFFORT BREAKDOWN

The process of authoring a Technical Order spans the entire contract period of a program. Through research, the author collects and evaluates information to gain a comprehensive knowledge of the component or system. This includes its operating principles, use, materials, and maintenance. The authoring process can be broken down into three major categories:

- Locating / Tracking Data -- Locating to sources of the data required to author the data, then tracking that source for changes.
- Researching / Assembling Data -- The process of interpolating the data to create the information required by the technician to maintain the system.
- Entering Data -- The actual process of entering the data into the authoring system.

We mailed surveys to one hundred technical publications professionals at McDonnell Douglas Aerospace requesting estimates of how they allocate their time to these tasks. Because the time to perform the above tasks can vary by the type of data being generated, the survey was broken down by the types of data contained in a T.O:

- Description and Principles of Operation
- Testing and Troubleshooting
- Schematics
- Procedural Data

The survey also collected information by type system (avionics vs. mechanical) and aircraft model (F-15, F-18, AV-8, and T-45). Forty two people responded to the survey. The results are shown in the accompanying table.

SURVEY RESULTS

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Locating / Tracking Data																					
Descriptive Data	new			20			20		40	20	35	50		10		20	10		15	30	
	update			30		10	5	20	40	20	30	30		15		10	10	60	15	30	
Testing &	new	10		20					40			50		10	15	20	10		20	30	
Troubleshooting Data	update	10		40		40		15	40			30		10	10	10	10		15	30	
Schematic Data	new			25			20		40			50	30	25	15	20	25		10	30	
	update			30		40	5	20	40			30	30	20	10	10	20	60	10	30	
Procedural Data	new	10	5	25	30		20		40			50			12	20	15		20		20
	update	20	25	35	30	20	5	15	40			30			10	10	15		15		15
AVERAGE		12%	15%	28%	30%	27%	12%	17%	40%	20%	32%	40%	30%	15%	12%	15%	14%	60%	15%	30%	17%
Researching/Assembling Data																					
Descriptive Data	new			60			50		50	35	25	30		70		50	50		55	40	
	update			40		30	40	70	55	35	30	50		65		55	60	25	45	40	
Testing &	new	40		40					50			30		75	48	50	50		40	50	
Troubleshooting Data	update	30		40		15		70	55			50		75	50	50	60		45	50	
Schematic Data	new			60			50		50			30	50	65	65	60	50		75	50	
	update			60		40	40	75	55			50	50	60	68	65	50	25	75	50	
Procedural Data	new	80	80	50	50		40		50			30			44	50	35		40		65
	update	60	50	45	50	30	20	70	55			50			45	50	50		45		75
AVERAGE		52%	65%	49%	50%	28%	40%	71%	52%	35%	27%	40%	50%	68%	53%	53%	50%	25%	52%	46%	70%
Entering Data																					
Descriptive Data	new			20			30		10	45	40	20		20		30	40		30	30	
	update			30		60	55	10	5	45	40	20		20		35	30	15	40	30	
Testing &	new	50		40					10			20		15	37	30	40		40	20	
Troubleshooting Data	update	60		20		45		15	5			20		15	40	40	30		40	20	
Schematic Data	new			15			30		10			20	20	10	20	20	25	15	15	20	
	update			10		20	55	5	5			20	20	20	22	25	20		15	20	
Procedural Data	new	10	10	25	20		40		10			20			44	30	50		40		15
	update	20	25	20	20	50	75	15	5			20			45	40	35		40		10
AVERAGE		35%	17%	22%	20%	43%	47%	11%	7%	45%	40%	20%	20%	16%	34%	31%	33%	15%	32%	23%	12%
Locating / Tracking Data		12%	15%	28%	30%	27%	12%	17%	40%	20%	32%	40%	30%	15%	12%	15%	14%	60%	15%	30%	17%
Researching/Assembling Data		52%	65%	49%	50%	28%	40%	71%	52%	35%	27%	40%	50%	68%	53%	53%	50%	25%	52%	46%	70%
Entering Data		35%	17%	22%	20%	43%	47%	11%	7%	45%	40%	20%	20%	16%	34%	31%	33%	15%	32%	23%	12%
	Avionics						X					X			X	X	X	X	X	X	
	Mechanical	X	X	X	X	X		X	X	X	X		X	X	X						
	F-15					X	X					X			X	X	X				X
	F-18	X	X	X	X		X	X	X	X	X		X		X			X	X		
	AV8						X							X	X	X	X				
	T45													X	X					X	

SURVEY RESULTS (Continued)

		21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	
Locating / Tracking Data																								
Descriptive Data	new	20		40		20	30		15	60			40	5	25	15				20	10	25	15	19%
	update	30			50	30	30		25	60			30	10	40	15		20			5	20	30	21%
Testing &	new	20			50	5	30		10	60				10	20	15			20	20	10	20	10	16%
Troubleshooting Data	update	30			50	5	20		20	60				10	30	15			15		5	15	20	20%
Schematic Data	new	20			50	15	40		20	60				10	10	10			30	30	5	20	25	18%
	update	30			50	15	30		25	60				5	50	10			25		5	20	35	21%
Procedural Data	new	20	30		30	70	30	20	15	60	40	50	30	20	20	15	30	10		30	10	20		25%
	update	30	30		40	70	30	20	25	60	20	30	30	20	20	15	25				10	15		21%
AVERAGE		25%	30%	40%	45%	28%	30%	20%	19%	60%	30%	40%	32%	11%	26%	13%	27%	15%	22%	25%	7%	19%	22%	22%
Researching/Assembling Data																								
Descriptive Data	new	70		40		30	40		25	30			40	75	50	50				40	70	75	40	55%
	update	45			20	30	40		25	30			40	65	30	40		50			75	75	15	49%
Testing &	new	70				75	40		30	30				65	60	50			60	60	60	70	45	59%
Troubleshooting Data	update	45			40	75	40		20	30				65	50	40			65		65	75	20	54%
Schematic Data	new	70				80	40		40	30				75	80	75			60	60	85	75	60	71%
	update	45			40	80	40		20	30				80	30	75			65		85	75	55	66%
Procedural Data	new	70	50		20	25	40	30	25	30	40	40	60	60	60	60	45			40	80	70		56%
	update	45	50		40	25	40	30	25	30	60	50	40	60	60	45	60	60			80	75		59%
AVERAGE		57%	50%	40%	32%	52%	40%	30%	26%	30%	50%	45%	45%	68%	52%	54%	52%	55%	62%	50%	75%	73%	39%	55%
Entering Data																								
Descriptive Data	new	10		20	40	50	30		60	10			20	20	25	35				40	20	10	45	27%
	update	25			30	40	30		50	10			30	25	30	45		30			20	5	55	30%
Testing &	new	10				20	30		60	10				25	20	35			20	20	30	10	45	26%
Troubleshooting Data	update	25			10	20	40		60	10				25	20	45			15		30	10	60	29%
Schematic Data	new	10				5	20		40	10				15	10	15			10	10	10	5	15	11%
	update	25			10	5	30		55	10				15	20	15			10		10	5	10	12%
Procedural Data	new	10	20		50	5	30	50	60	10	20	10	10	20	20	25	25			30	10	10		18%
	update	25	20		20	5	30	50	50	10	20	20	30	20	20	45	15	30			10	10		22%
AVERAGE		17%	20%	20%	26%	18%	30%	50%	54%	10%	20%	15%	22%	20%	20%	32%	20%	30%	13%	25%	17%	8%	38%	22%
Locating / Tracking Data		25%	30%	40%	45%	28%	30%	20%	19%	60%	30%	40%	32%	11%	26%	13%	27%	15%	22%	25%	7%	19%	22%	**22%**
Researching/Assembling Data		57%	50%	40%	32%	52%	40%	30%	26%	30%	50%	45%	45%	68%	52%	54%	52%	55%	62%	50%	75%	73%	39%	**55%**
Entering Data		17%	20%	20%	26%	18%	30%	50%	54%	10%	20%	15%	22%	20%	20%	32%	20%	30%	13%	25%	17%	8%	38%	**22%**
Avionics														X	X	X			X		X		X	
Mechanical			X		X	X	X	X	X	X	X		X				X	X		X		X		
F-15		X			X				X					X	X	X			X		X			
F-18			X	X			X	X		X	X	X	X	X	X		X			X		X	X	
AV8					X	X								X				X						
T45					X	X																		